Watershed Management

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Module No. # 07

Lecture No. # 28

Groundwater Pollution Problems and Transport Processes

Welcome back to the video course on watershed management in module number 7 on management of water quality. Today, in lecture number 28, we will discuss about groundwater pollution problems and transport processes.

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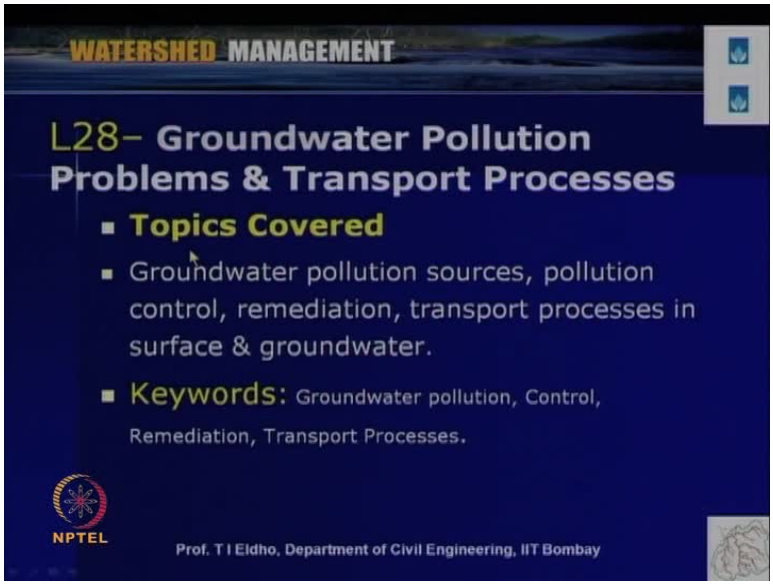

Some of the important topics covered today include - groundwater pollution sources, pollution control, remediation, transport processes in surface and groundwater. Some other keywords for today's lecture: groundwater pollution, control, remediation and transport processes.

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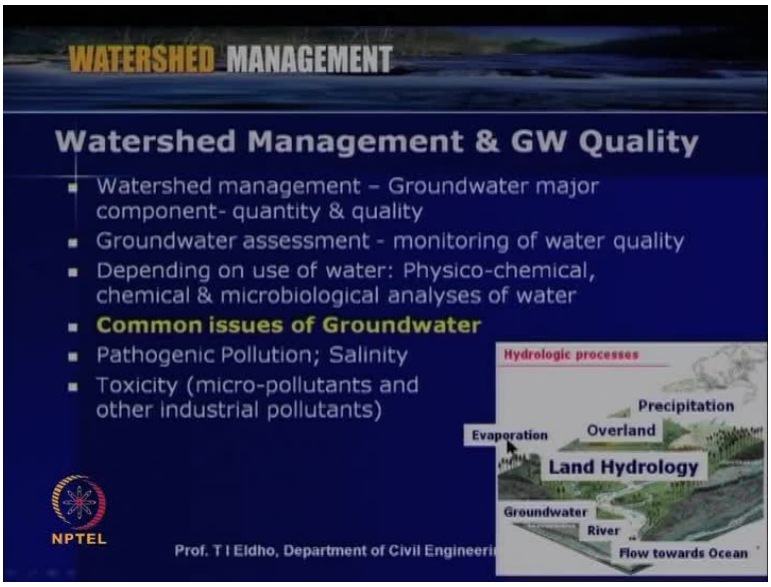

As we discussed earlier, when we deal with the water management, say within a watershed, we have to deal with the surface water and the groundwater. So, it is not only the quantity of water that has to be made available to the flora and fauna, to the people within the watershed and we have to see the quality of the water. As we discussed in the previous lecture, the water quality is a major issue, surface water quality and as well as groundwater quality are major issues, which we have to deal nowadays.

Due to various reasons, the quality of groundwater or surface water is deteriorated very much. In today's lecture, we will see the problems related to the grounder water quality. In the last lecture, we have discussed about the surface water quality issues. When we deal with the watershed management, groundwater is a major component as far as water source is concerned. Groundwater is a part of the hydrological processes, which we have already considered. So, with respect to the infiltration, water is joining to the water table or the aquifer systems and that will be interacting within the systems.

In that way, whatever is happening within the surface and if any pollution source is there within the surface of the planet or within the surface of the watershed, then that will also be affected. It is not only to the surface water, but to the groundwater also. When we deal with the watershed management, the groundwater quality is also a major issue. So, groundwater assessment have to be done with respect to the quantity and we also have to do the monitoring of the water quality.

As we discussed in the previous lecture, as far as water is concerned, we have to see the way how much pollution is there within the water or whether any the water quality meets certain standards for various purposes like drinking purpose, irrigation purpose or domestic purposes. So, like that we have to see whether the available water quality is safe for the proposed use.

Depending upon the use of water, we have to do the Physico-chemical, chemical and microbiological analysis of water. As we discussed in the last lecture, physical analysis, chemical analysis and microbiological analysis are there to see that the water quality standards have been met. As far as groundwater is concerned, it is very similar to the surface water, since both the surface water and groundwater are interacting within the hydrology processes. Some of the pollutant source includes the toxicity like micro-pollutants, other industry pollutants, pathogenic pollutions, salinity problems. Like that these are some of the common issues as far as groundwater quality is concerned.

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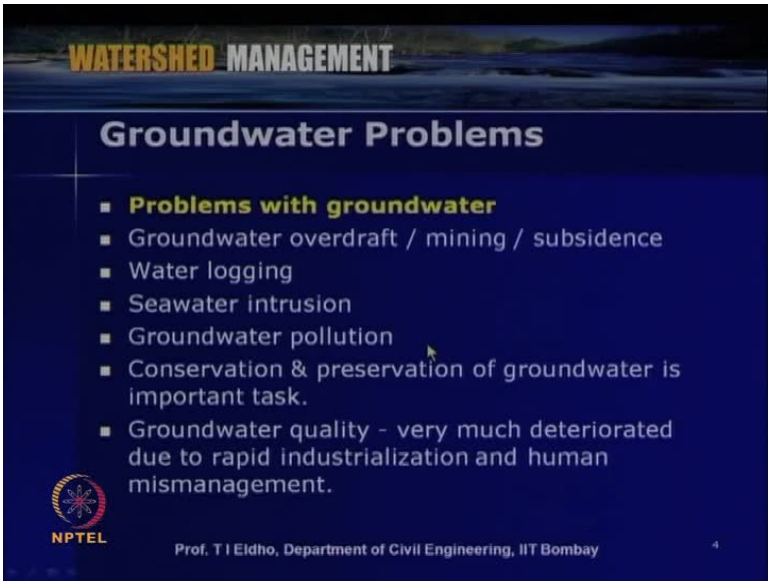

Now, let us look into the detailed aspects of groundwater, say quality related problems. So, the problems with groundwater, as we discussed in earlier lecture, in some locations of the planet of the earth, people are using too much groundwater. In that way, overdraft is some of the issue and water table is going down.

The issues related to mining, especially when the mining operation produces lot of wastewater. It is polluting the aquifer systems or the groundwater systems, then a subsidence like water logging problems. Wherever the water table rises beyond certain level, then water logging and its related problems are there in agriculture and other areas. Coastal aquifer problems like seawater intrusion, so the salt water mixes with the pure groundwater and the groundwater become useless or we cannot utilize for the purpose, which we are looking for. So that way groundwater pollution has become a major concern in the last few decades throughout the world. Nowadays, the groundwater hydrologist are always thinking on how we can preserve or conserve the existing groundwater source, which is always the annual base and it is recharged due to the rainfall and other sources.

We have to conserve and preserve, so that the water quality standards are met for either for drinking or any other purposes, which we are looking for. In the last few decades due to industrialization and various other human made problems, the groundwater resource has been assaulted in different ways and then the quality of the groundwater in many locations have gone down. So, the groundwater quality is very much deteriorated due to rapid industrialization and human mismanagement. We can call this as human mismanagement; it is not happing due to the natural courses, but due to the human interventions within the system and it is not appropriately done. So, these are some of the major reasons as for as the deterioration of the groundwater is concerned.

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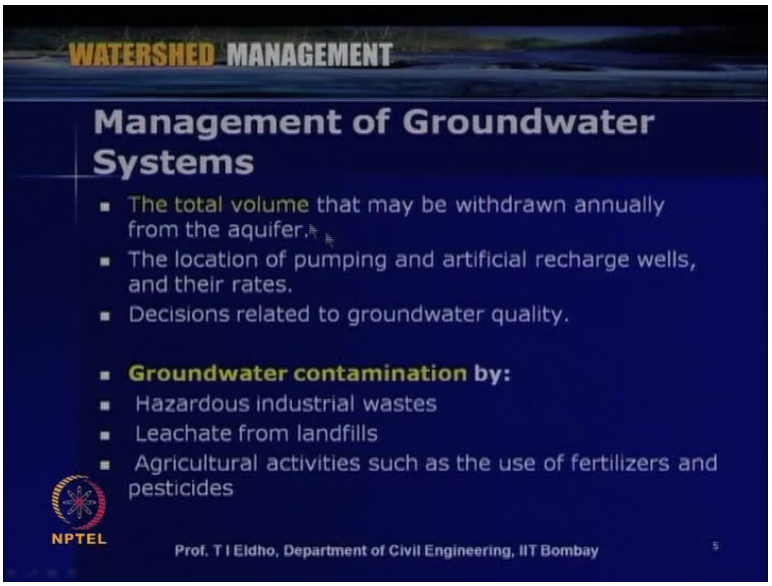

When we deal with the groundwater, as we discussed earlier, when the management of groundwater systems is concerned, we have to deal with the quantity of the groundwater and the quality of the groundwater. As far as quantity is concerned, the total volume that may be withdrawn annually from the aquifer. We have to see that there is a balance between what is recharged and what is withdrawn from the aquifer systems, so that the groundwater table will not go down drastically, location of pumping and artificial recharge wells and their rates. If you consider an aquifer systems depending upon the recharge rates, how much we can pump out of the aquifer systems. If you are going for recharging, how much we have to recharge with respect to the available water.

All these things deal effectively for groundwater management. So, we have to take certain decisions as far as the groundwater quantity is concerned and groundwater quality is concerned. As I mentioned, even if the sufficient quantity is available or if the quality of the groundwater is not good, we cannot use for the purpose, which is meant for. So, we have to take decisions related to groundwater quality. As I mentioned, groundwater contamination can be due to various sources like hazardous industrial wastes, leachate from landfills, agricultural activities such as the use of fertilizers and pesticides.

As we have discussed in the last lectures, these kinds of pollutions can be either point source pollutions or the non-point source pollutions. Point source is directly coming from underground tanks, where leakage takes place and that is going to the aquifer systems or where the groundwater is affected that is point source. Non-point source like agricultural sources, nutrients or herbicides or pesticides and these kinds of pollutions are non-point source of pollutions. So, we have to deal the groundwater systems effectively. In that way, we have to say that groundwater systems has to be managed effectively as far as quantity and quality are concerned.

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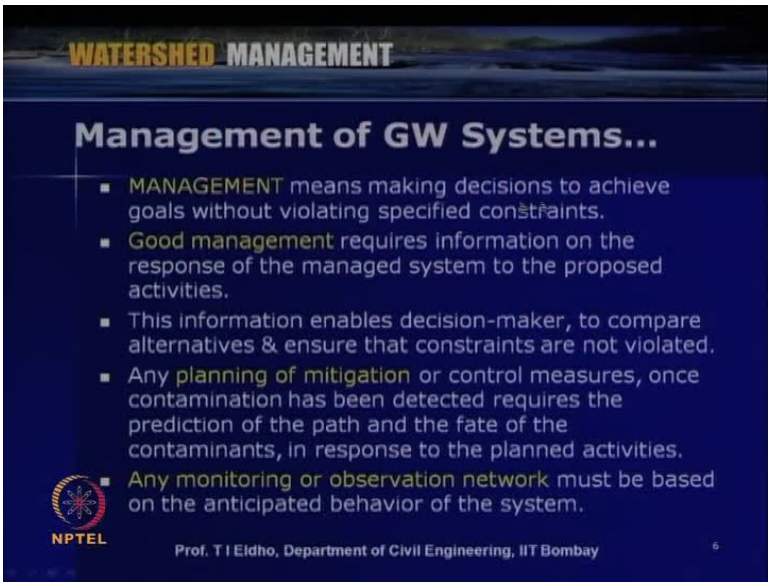

Management means making decisions to achieve goals without violating specified constraints. For example, from a given aquifer, if you want to pump out 1000 meter cube per day, we have to see that the objective is to meet that 1000 meter cube per day. We have to see that certain constraints like the groundwater level should not fall below certain specified limits or the quality of the groundwater should be good enough with respect to the standards for the drinking water or the agricultural purposes, so that should be met.

We have to see that specified constraints are met. So, good management requires information on the response of the managed systems to the proposed activities. Here, it means the aquifer systems or groundwater systems. If you are pumping this much water, what happens for the quality? If contamination is going through the groundwater system, how is it spreading and what will be the affects? So, this information enables decision maker to compare alternatives and ensure that constraints are not violated. So, say for example, if there is a pollutant source to the aquifer systems and you pump water for drinking purpose or water supply purpose from that aquifer system.

How to say whether there will be an interaction? How we can manage this? The decision maker has to take a decision by considering various options like groundwater modeling or groundwater pollutant modeling or contamination transport modeling. Planning of mitigation or control measures - once contamination has been detected requires the

prediction of the path and the fate of the contaminants in response to the planned activities. If you are going from the control measures, we have to see that how much portion of the groundwater system is affected or where the plume is moving and at what rate it is moving, whether that will reach the pumping well, which we are pumping for water supply or other purposes. So, we have to see all these issues.

Any monitoring or observation network must be based on the anticipated behavior of the system. Through groundwater modeling, we can identify the anticipated behavior of the system. If you are having a monitoring or observation network, through that we can identify what is the best way to manage the groundwater systems as far as the groundwater pollution is concerned.

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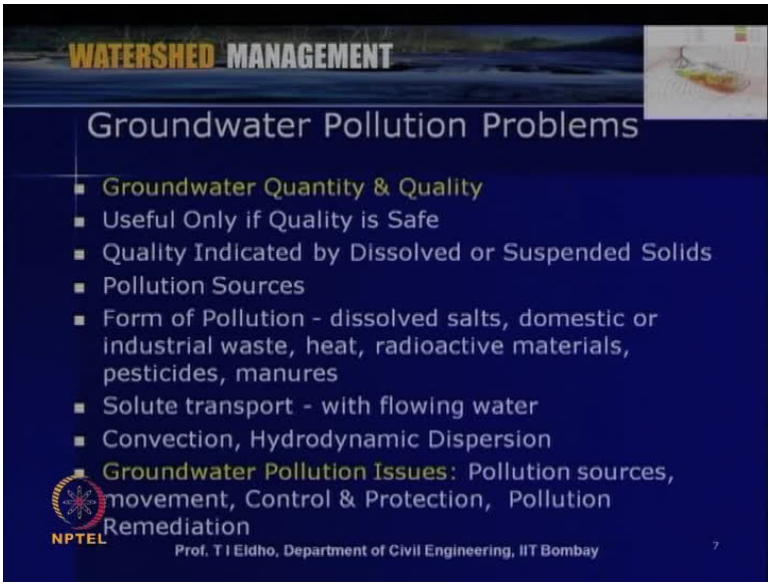

Now, whatever we are discussing is related to groundwater system management with respect to quantity or quality. Now, let us go to the details of groundwater pollution sources, then pollution control and the remediation aspects. Groundwater pollution problems - as I mentioned, when you are dealing with the water resource in a watershed, we have to see that not only that sufficient quantity of water is available, but quality is also good enough. So, water is useful only if quality is safe, so that is a very important aspect.

Quality is indicated by, as we discussed in the previous lecture that the various indicators like dissolved or suspended solids or the whether the water is basic or acidic say like pH indictor or we say the biological quality. When we discuss watershed basis or a river basins basis or aquifer basis, we have to see that what are the important sources of pollution. We have to see what are the important forms of pollutions, whether the form is dissolved salts or domestic or industrial wastes or whether heat pollution or radioactive materials, pesticides, manures etc.

What is a source of pollution? What kind of pollution is there? What is the form of pollution? How the pollutant or the contamination is moving within the aquifer system? So, pollutant transport or solute transport generally takes place with the flowing water. In the aquifer system, groundwater is moving from one location to another location, according to the hydraulic gradients and other parameters. So, we have to see how that solute is transported. As we discussed earlier, process like convention, hydrodynamic dispersions and all these controls the groundwater pollutant movement or the contamination movement within the aquifer systems.

Groundwater pollution issues - when we discuss about the various issues related to groundwater pollution, we have to see some of the important things like pollution sources, pollutant movement or contaminant movement, how we can control the movement of the plume or contamination. How we can protect the groundwater systems and then wherever it is polluted, how we can remediate it, so that we can retrieve back? Even though it is not the original system original quality, but to certain extent we can remediate it. So, what kind of remediation are possible? All these issues have to be considered.

Groundwater pollution issues include source identification, we have to identify where the contamination is moving or moment of the contaminant is, control and protection and then pollution remediation. So, these are some of the important issues, which we have to consider when we deal with the groundwater pollution.

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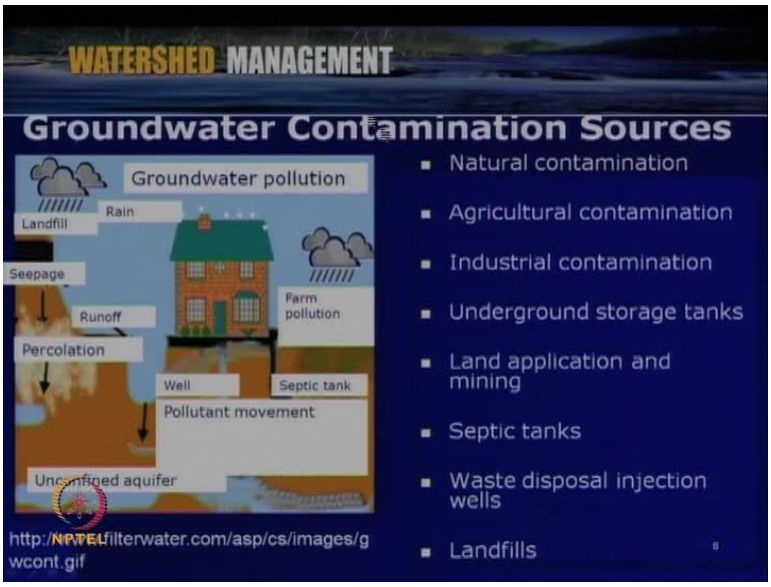

Now, let us look into the important sources of pollution. Groundwater contamination sources - some of the important contamination sources have been listed here like natural contamination, agricultural contamination, industrial contamination, underground storage tanks, land application and mining, septic tanks, waste disposal injection wells, landfills etc.

If this is the watershed or the area, which we are considering, it can be farms that is non-point source of pollutions. Septic tank or the landfills will seep and with respect to rainfall, the contamination will be seeping down and that will be joining the surface water or to the groundwater. So that way, various sources of pollutions are possible. We have to identify what are the important sources of pollution and then we have to deal with the corresponding source to control the pollution and for remediation.

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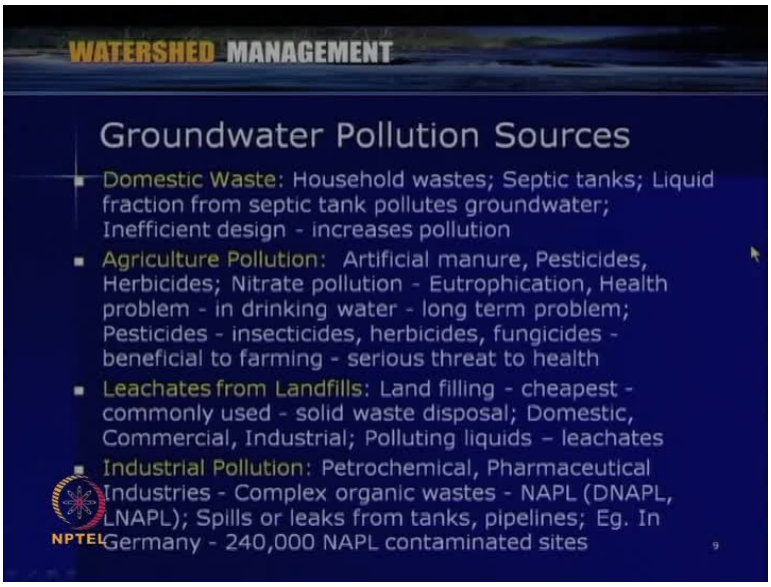

Now, let us look into various aspects of this groundwater pollution sources. As I mentioned, we have already discussed the important sources of pollutions. First one is the domestic waste. Domestic waste can be like household waste, septic tanks, liquid fraction from septic tank pollutes groundwater, then inefficient design increases pollution. Especially household waste and the sewage water coming from the house are most of the time directed to drain or to the surface water or the drainage systems, so that can mix and can penetrate down or infiltrate down to the aquifer system. Domestic waste can be a source, where septic tanks are there. Leakage can be related to septic tanks, so that can be a source of pollution.

Agricultural pollution - as we discussed in the previous lecture, artificial manure, fertilizers, pesticides, herbicides, nitrate pollution, eutrophications, health problems, drinking water, long term problem. The nitrates and all those kinds of pollutants or long term source of pollution, then pesticides - insecticides - herbicides - fungicides and all these things are beneficial to farming, but causes serious threat to the surface water and the groundwater.

Once the surface water is polluted, it will be interacting with the groundwater systems and that will become source of pollution, then only agriculture pollution is concerned. It can be non-point sources of pollution, especially in urban areas as far as the solid waste is concerned. Most of the cities or towns use landfills and these solid wastes will be

collected in trucks and deposited in landfills. If the landfills are not scientifically done, proper measures are not taken, then from the landfill, a liquid called a leachate is produced when these rain water mixes with the contaminate source and within the landfill. It can penetrate down to the aquifer systems or the groundwater systems and that can be the source of pollutions. The third one is leachate from landfills, so it is one of the commonly used cheapest solutions for solid waste. It can be say for domestic related or commercial or industrial. So, this polluting liquid is called leachates and it is a major source of pollution as far as the groundwater system is concerned.

The next major source is industrial pollution. Industrial resources like petrochemical industries, pharmaceutical industries. All these produces complex organic wastes like non-aqueous phase liquid; it can be dense or light, spills or leaks from tanks, pipelines. All these cause the pollutant sources either directly coming on the soil surface or can penetrate down or infiltrate down to the aquifer systems. It can be a source of pollution to the groundwater systems or where, surface ground water pollution is there. When surface and groundwater interaction takes place, it becomes a source of groundwater pollution. For example, in Germany, it is identified that it has above 240000 non-aqueous phase liquid contaminated sites at various industrial sites, so that way this industrial pollution is a major source of pollution.

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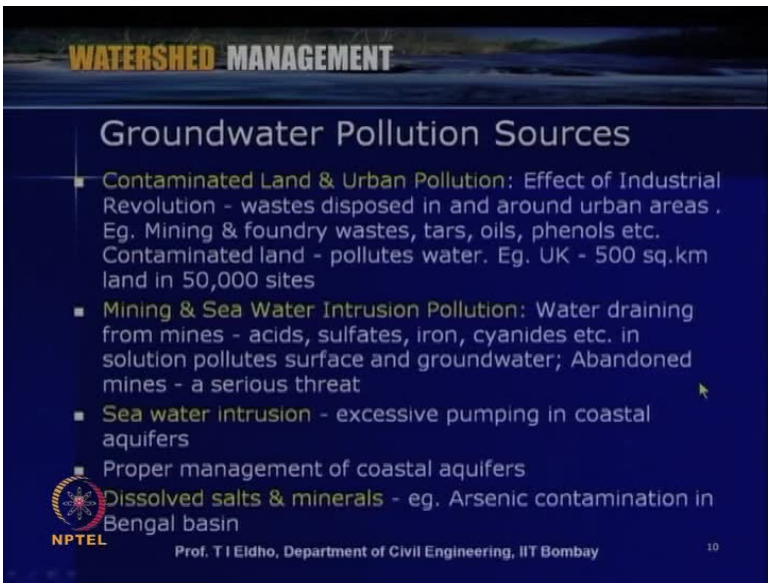

Contaminated land and urban pollution - Effect of industrial revolution like waste disposed in land around urban areas, example mining and foundry wastes, tars, oils, phenols etc. These all are sources of pollution as far as the subsurface water or groundwater is concerned. In United Kingdom, it is identified that about 500 square kilometer of land is polluted. Soil is polluted about 50000 sites and in this, whenever the water that runoff with respect to rainwater and this water mixes with these sites. The contaminations will be formed as a plume and that will be moving through the subsurface or the subsurface water and that will be becoming a source of pollution as far as the groundwater is concerned.

Mining and sea water intrusion pollution - water draining from mines like the nature of this water will be acids, the sulphates. So, lot of pollution will be there like acidic or sulphate pollution, iron pollution, cyanides etc. This will be in solution and this pollutes surface and groundwater. That becomes a source of pollution as far as the groundwater is concerned and abandoned mines is a major threat for the groundwater as I mentioned, sea water intrusion, say excessive pumping in coastal aquifers. In that way, the sea water endure to the coastal aquifers and that the mixes with the groundwater in the coastal region and it becomes a source of pollution.

We have to look, so that the overdraft of groundwater should not be allowed in the coastal areas or coastal aquifers, so proper management measure should be adopted. Dissolved salts and minerals like arsenic contamination in Bengal basins and this arsenic contamination are in coast due to over drafting of the groundwater. So, due to that say, certain minerals or certain salts within the soil leach and that become a source of pollution. So, dissolved salts and minerals are also another source of pollution.

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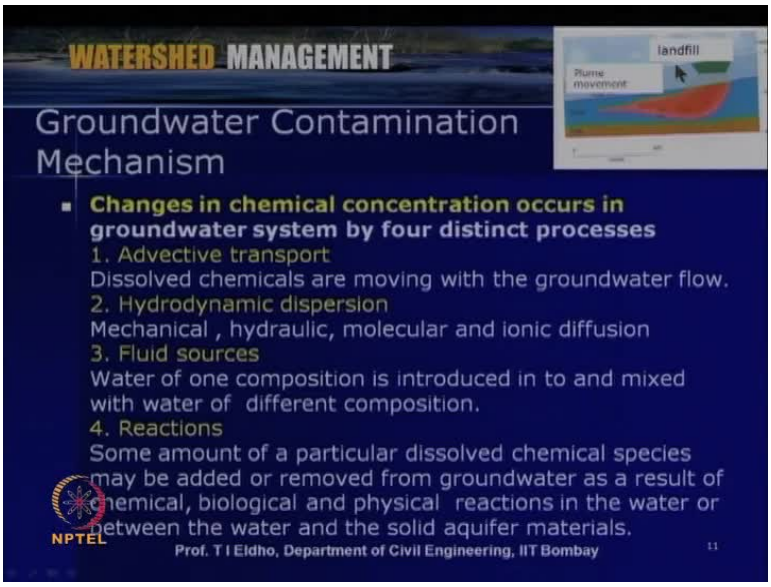

Let us look into what is the mechanism that is happening where there is groundwater contamination. We have seen various sources of pollution, for example as shown in this figure, the landfill is there and leachate is there. So, with respect to the movement of the groundwater, this contamination plume is moving. The changes in chemical concentration occur in groundwater system for distinct processes, mainly for the Advective transport. It means that when the groundwater is moving with respect to the movement of the groundwater contaminations like dissolved chemicals are moving with the groundwater flow.

Hydrodynamic dispersion- mechanical, hydraulic, molecular and ionic diffusion. Various intermixing within the pores takes place, diffusion dispersion and all these process takes place. So, hydrodynamic dispersion is another important mechanism of the pollutant movement or plume movement. Fluid sources like water of one composition is introduced and mixed with water of different compositions. If you are keeping some kinds of oils or other kinds of chemicals in a tank in underground, so that may mix due to any leakage that can mix. So, fluid sources can also be under certain pressures. This will be moving through the aquifer system.

Water of one composition is introduced into and mixed with water of different composition. So, all the polluted water from the surface water can be another source as far as the groundwater is concerned, so that is fluid sources. Reactions - some amount of

particular dissolved chemical species may be added or removed from groundwater as a result of chemical biological and physical reactions in the water or between the water and the solid aquifer materials.

Whatever the contamination is there within the aquifer systems, it can change its phase due to various reactions between the chemicals like the radioactive pollutant material. After sometime, the material become another phase or multi-phase liquid movement. It may interact and various kinds of chemicals can interact due to reactions, so the nature of the contamination itself can change. As far as groundwater contamination mechanisms are concerned, important mechanisms are advective transport, hydrodynamic dispersion, fluid sources and reactions. So, related to these transport process, we will be discussing these details in this lecture itself. Now, what we discussed is we have seen the groundwater pollution sources and what is the mechanism of this plume movement or contamination spreading.

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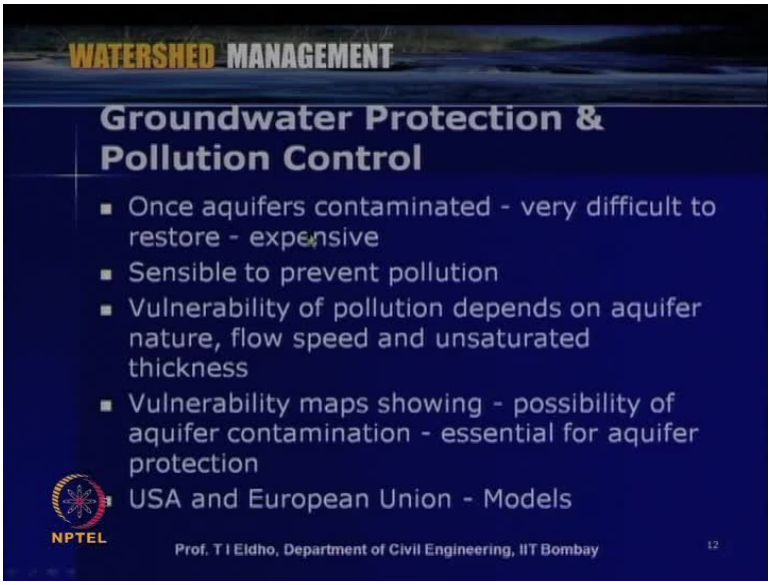

How we can protect the groundwater or how we can control the pollution? Let us look briefly into various pollution control measures. Once aquifers are contaminated, it is very difficult to restore; it is very expensive process. So, it is always sensible to prevent the pollution.

Vulnerability of pollution depends on aquifer nature like the hydraulic conductivity, what kind of soil is there and what type of contamination is there. So, there are many parameters depending upon which, the vulnerability may be serious or mild vulnerability. So, flow speed and unsaturated thickness and all these things. We can prepare vulnerability maps showing possibility of aquifer contamination, for example, if there is an industry or if there is a source of pollution that is identified for the particular aquifer systems or particular area particular watershed, we can prepare vulnerability maps. Within these many days, this is the area, which may be polluted or if these kinds of leakage takes place, these are the possibilities, so like that we can have vulnerability maps.

Actually in many countries like United States of America and European countries like Germany, Netherlands and United Kingdom; these countries have prepared such kinds of vulnerability maps. In many of these countries, groundwater is one of the important sources of water supply, so that way to protect this groundwater, they have prepared the groundwater vulnerability maps. From these maps, we can identify whether this particular aquifer system is vulnerable and what kind of measures can be taken to protect the groundwater as a resource. We have seen that various sources of contamination is there. If we can control the source itself through various strategies, then we can reduce the groundwater pollution.

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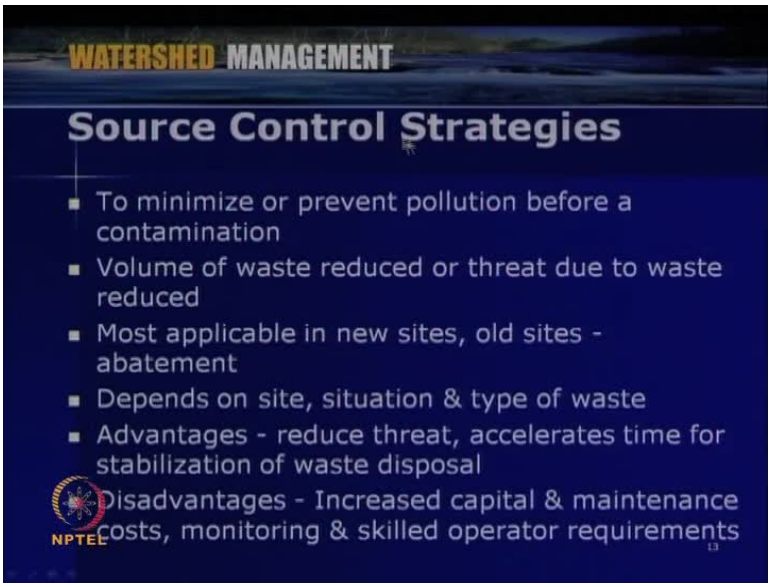

Let us look into some aspects of sources of control strategies to minimize or prevent pollution before a contamination. This is the main aim of the source control strategies, so volume of waste is reduced or threat due to waste reduced. Either solid waste or liquid waste can be reduced, so that the vulnerability is reduced. This is mostly applicable in new sites, but in all the sites, we can reduce the abatements and the spreading can be reduced. The source control strategies depends upon the hydrologic parameters of the site, how much area is product, the situation and what kind of contaminated plume or type of waste. Depending upon that we can adopt typical type of source control strategies like to minimize the pollution or to protect the systems.

Some of the advantages of the source control strategies includes, it reduce the threat to the groundwater pollution, accelerates time for stabilization of waste disposal. Some other disadvantages include increased to capital and maintenance cost, since we have to spend money to control the source, so that will not spread to the aquifer systems or to the groundwater system. We also have to go for monitoring that once the source is controlled, whether any possibility of further leakage or further movement or contamination is there. So, we have to monitor the system with skilled operators and these are some of the disadvantages.

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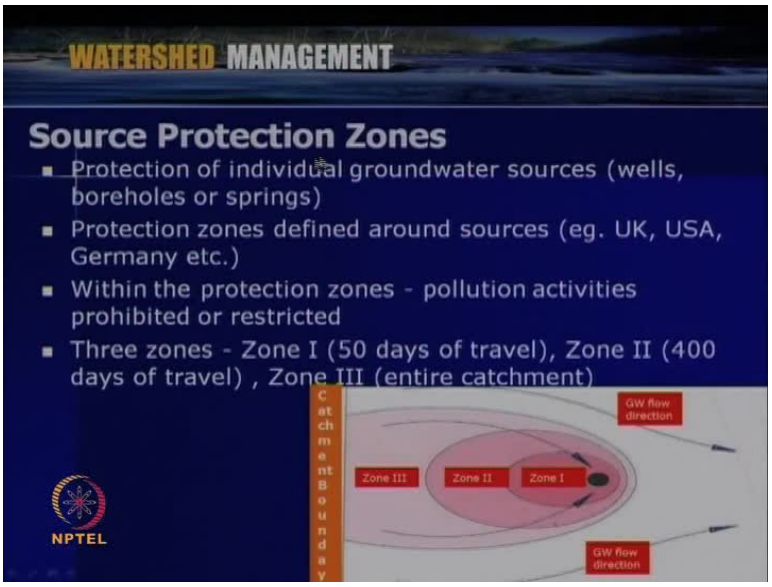

Another model, which is tested in many of the European countries and in USA is Source resource protection zones. Here, in this slide, you can see that if this is the total

catchment of the aquifer systems from where the groundwater is pumped for various purposes. Actually, we can have protections of individual groundwater sources like if particular well is there or boreholes or springs, we can go for protection measures. So, we can define the protection zones like what is done in United Kingdom, USA, Germany etc for the sources, if this is the pumping well.

We can have generally have three types of protection zones - the first zone is this; the first zone is in this countries, for example, 50 days of travel time of the water that is one particle of water to reach this well in 50 days. We can delineate the zone and then absolutely no kinds of pollutant or industrial activities or any activities are allowed in the zones and water pumped from this area is protected, so that is zone I. Zone II is actually the area, where 400 days of travel time are there for the water particles. Various activities are allowed in a controlled way, so that there is no scope for groundwater pollution in that area.

The last one is the zone III, where entire catchment itself…, wherever the water is used for drinking or for the water supply purpose, then we can declare that in the zone, certain kinds of activities, certain pollutant causing industries can be stopped. As I mentioned, we can have three zones and then we can have within this protections zones. Pollution activities are prohibited or restricted in zone I, zone II and zone III as discussed.

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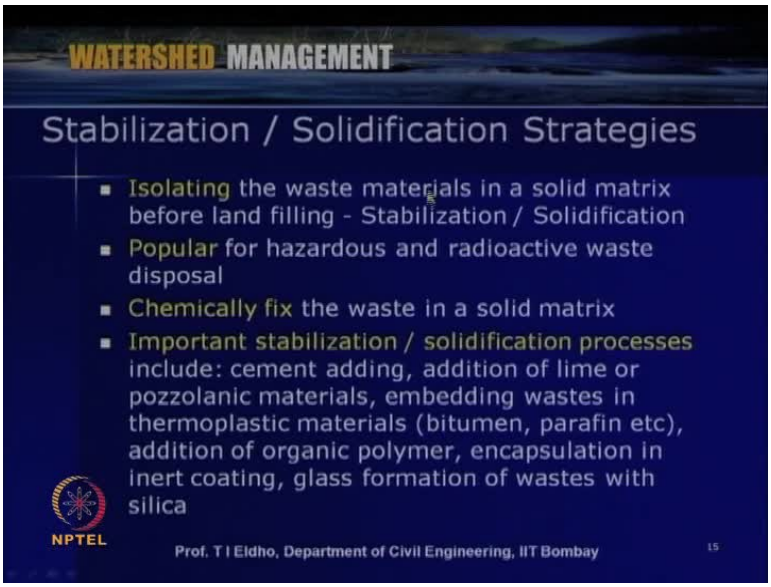

As far as the contamination is concerned, we can go for stabilization or solidification strategies. In this pollution control strategies, we can isolate the waste material in a solid matrix before land filling. So, the Stabilization solidification strategies are very effectively used in many countries, then this kind of methodologies are popular for hazardous and radioactive waste disposal. Especially in radioactive, we can isolate and then put it in a (( )) and then put it in a very deep say rocky area underground, so that there is no scope for any kind of pollution.

We can chemically fix the waste in a solid matrix. If the particular type of contamination is it is if it is possible to say mix with certain other chemicals, so that material become inert and there is no source of pollution. That process is called chemically fix - the waste in a solid matrix. Important stabilization or solidification processes includes cement adding, addition of lime or pozzolanic materials, embedding wastes in thermoplastic materials like bitumen or paraffin, addition of organic polyester, encapsulation in inert coating, glass formation of wastes with silica. There are number of techniques for stabilization or solidification. Depending upon the contamination material or pollutant source, we can go for specified stabilization or solidification strategies. In that way, we can control the pollutants source, so that the groundwater can be protected.

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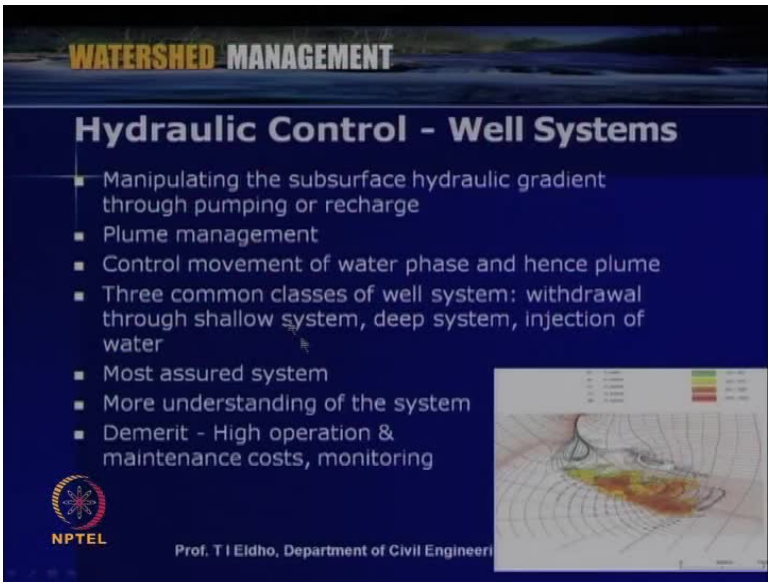

Another commonly used technique is called hydraulic control. As shown in this slide, we are manipulating the subsurface hydraulic gradient through pumping or recharge. For

example, if this is the contaminant plume and if there are certain wells pumping the water for water supply, we restrict these movement of this contaminant plume towards the pumping well through certain pumping or recharging at various locations. So, this process is called hydraulic control through well systems. This is actually plume management.

We control the movement of water phase and hence plume. So, the plume movement is controlled. Generally, three common classes of well systems are used like withdrawal through shallow systems, deep systems and then injection of water. We can either do it through pumping of the water or injection, so that appropriate hydraulic gradient is generated within the aquifer system. This contaminant plume movement is restricted, it will not go to the nearby area of the pumping well, but its movement will be restricted.

Actually, this is one of the most assured systems, but there should be good understanding of the systems through groundwater stimulation and aquifer characterization. So, the demerit is high operation and maintenance costs, since we have to either pump water or recharge and then continues monitoring is required. This methodology is called hydraulic control or so called well systems.

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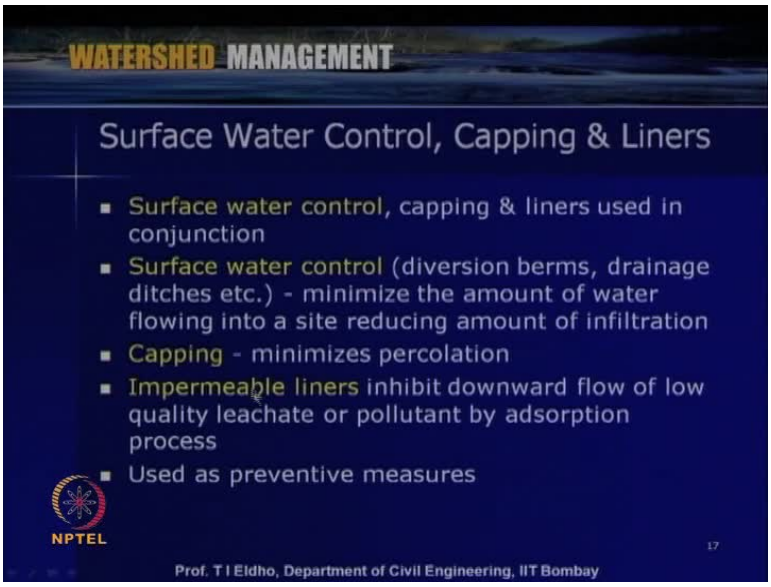

Some other techniques like surface water control, capping and liners. So, these are also used in many countries for the groundwater protection or groundwater pollution control.

Surface water control, capping and liners are used in conjunction with each other. So, what we do is the surface water, which is polluted. We can control its movement and we can give certain capping or lining, so this contaminates water is not moving to the aquifer systems.

Another one is surface water control, where we can construct certain diversion berms, drainage, ditches etc, so that the polluted water is not mixing to the aquifer systems. This minimizes the amount of water flowing into a site, thus reducing the amount of a infiltration. We can go for capping, so that the area is capped and further contamination is not taking place or the plume movement is restricted. We can also go for impermeable liners, which inhibit downward flow of low quality leachate pollutant by adsorption process. We can have certain impermeable liners using clay or other materials, so that will not allow contaminate plume or contaminate source to reach the pure water source or the aquifer systems. All these are used as preventive measures, so that we can control the pollutant movement and then we can protect the aquifer systems or the groundwater systems.

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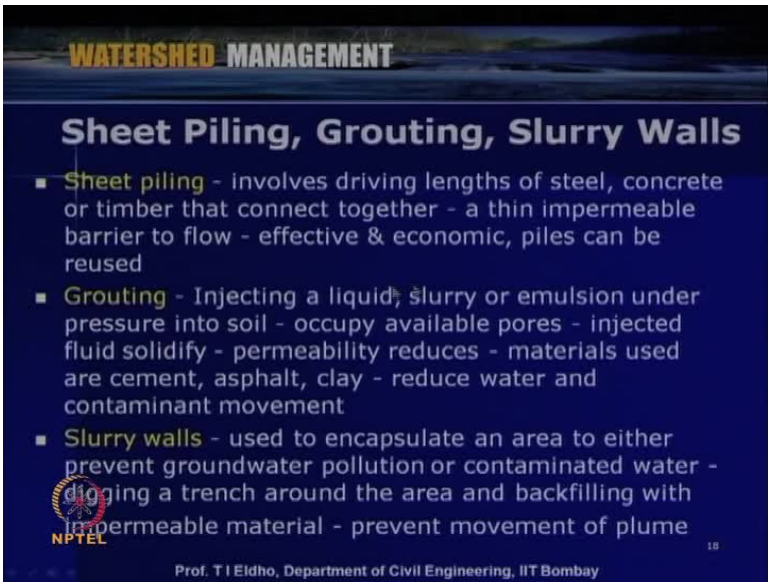

Some of the other techniques is used are sheet piling, grouting and slurry walls. Here, this sheet piling involves driving lengths of steel or concrete or timber that connects together a thin impermeable barrier to flow. So, this is effective and economic. Piles can be reused, so we can control the movement of the pollutant. Grouting means injecting a

liquid slurry or emulsion under pressure into soil. So, this occupies available pores and injected fluids solidify, so that the permeability reduces. Generally, materials used are cement, asphalt, clay. So, this reduce water and contaminant movement, so that the plume will be stopped at particular locations.

Another technique is called use of slurry walls. Slurry walls are used to encapsulate an area to either prevent groundwater pollution or contaminated water. So, digging a trench around the area and then backfilling with impermeable material prevents the movement of plumes. As we discussed, surface water control, capping and liners can be using sheet piling, grouting, slurry walls etc.

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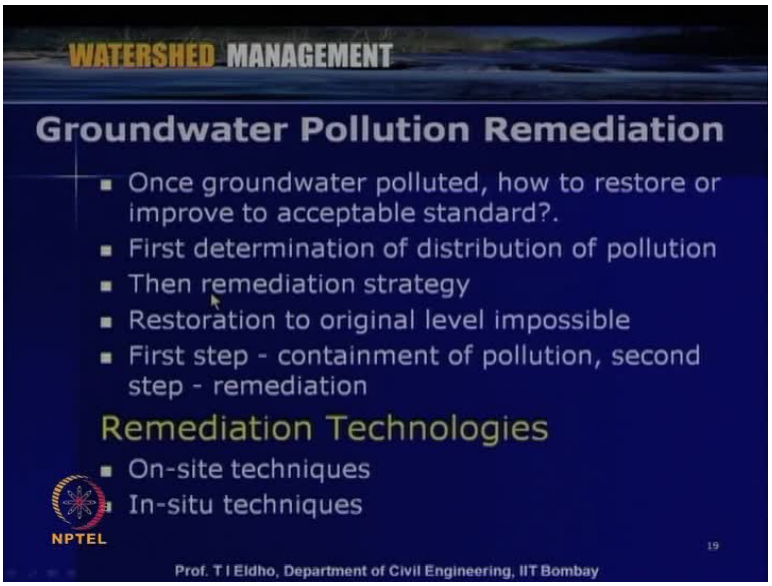

Now, what we are discussing is groundwater pollution sources, the mechanism - movement of the pollutant and how we can protect the groundwater systems or we can control the pollutant movement. Now, once the groundwater system of the aquifer is polluted, what we can do, so that process is called groundwater pollution remediation? We are trying to remediate or we remove the contamination from the aquifer systems or from the groundwater system, but this is a very complex process and it is also very expensive.

Once groundwater is polluted, the question is how to restore or improved to acceptable standard, whether it is depending upon the use; whether it is for irrigation or any other

purpose, how we can get to the acceptable standard? For this, we have to study the system thoroughly. First, we have to determine the distribution of pollution, we have to design a remediation strategy. As I mentioned, once an aquifer is polluted and making it to the actual original level is impossible task, but we can do certain measures, so that the contamination can be reduced to certain level with the aquifer systems or the groundwater can be remediated.

All these process are- the first step is we have to stop. Once a contamination is identified; the contaminant plume is identified, we have to contain that pollution or containment of the plume. Second one is we have to go for remediation. Contamination is also very important in the plume movement. We have to contain, otherwise again it will spread through the aquifer system. So, first step is containment and second one is the remediation.

Generally, for groundwater pollution remediation, two types of technologies or techniques are used. First one is called on-site techniques and second one is called a in-situ techniques. On-site techniques generally mean that it will be pumping out the polluted water from the aquifer systems. We can treat it and either put it back to the aquifer systems or we can use it or we can spill to the nearby surface water sources like lakes or rivers.

The second one is called in-situ technique. We are not pumping out the polluted water; we are adding some material like bioremediation or air sparging or various techniques, where in-situ is there, where the hot spot or contaminations are there. We are trying to remediate, so that is the technique and it is called as in-situ techniques.

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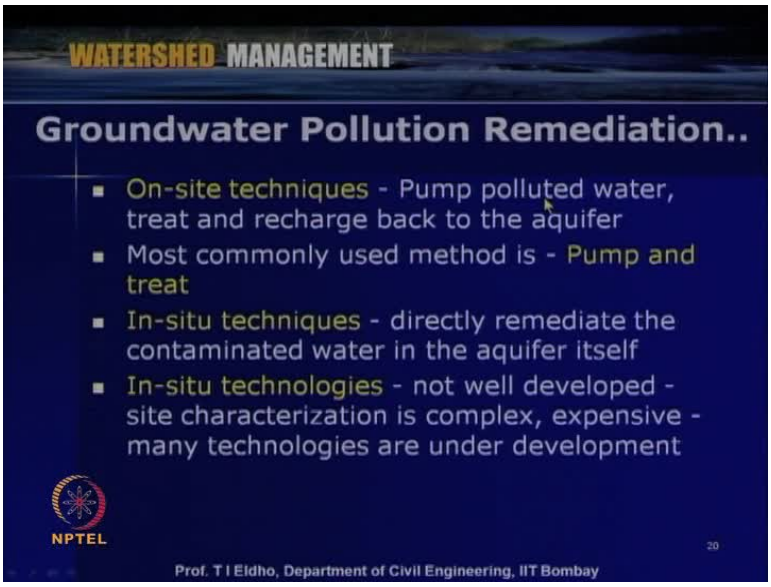

As I mentioned here on-site techniques, we generally pump the polluted water, treat and recharge back to the aquifer systems. So, one of the most commonly used methods are pump and treat. So, we pump the polluted water, treat it and either use it or put it back. In in-situ techniques, we directly remediate the contaminated water in the aquifer itself. In in-situ technologies, we do not know the actual total groundwater system or subsurface system, so that way it is called as complex process.

These in-situ technologies are still under development, so it requires complete site characterization, but it is very complex process and expensive. So, many technologies are under development as far as in-situ technologies are concerned. We will have an overview of some of the important techniques used on-site, which is called pump and treat. We will have a brief review in this lecture on some of the in-situ technologies.

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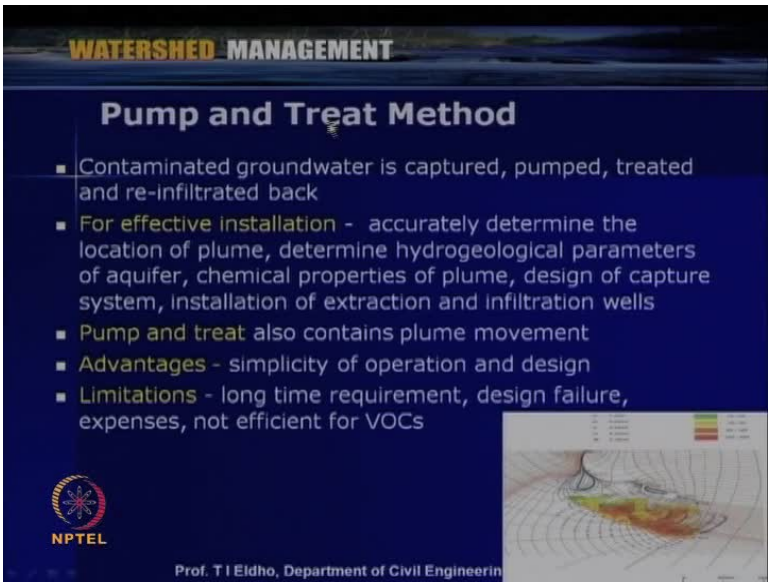

As I mentioned, one of the most commonly used treatment technology is on-site technique of pump and treat. So, what we do is the contaminant plume, wherever it is there in the hot spot, through boreholes or through wells, we pump this polluted water out of the aquifer systems. We treat it outside depending upon the contamination and then we can either pump it, recharge back to the aquifer system or we can use it or we can spill it to the nearby sources surface water sources.

The contaminate groundwater is captured, pumped, treated and re-infiltrated back. So, for effective installation, accurately we have to determine the location of the plume. So, this plume location is very important and accordingly only we can design a pump and treat system. We have to determine the hydrogeological parameters of the aquifer like hydraulic conductivity, porosity, chemical properties of the plume, design; we have to design the capture systems, installation of extraction and infiltration wells. If you are going to infiltrate back to the aquifer systems, we have to also design the infiltration wells.

This pump and treat, as we discussed earlier is also a plume management or we can also used to contain the plume at certain locations. As we discussed earlier, some of the advantages of this pump and treat on-site technique includes that it is simple to operate and design is simple. Some of the limitations for long time are that depending upon the area, depending upon the contamination, it may require many years to remediate an

aquifer system, there is possibility of design failures. So, the wells are not located properly or the pumping rate is not proper, the pump and treatment may not become successful, it is very expensive. For example, what are the organic contaminates for which this pump and treat may not be so effective? So, these are some of the limitations as far as the pump and treat is concerned.

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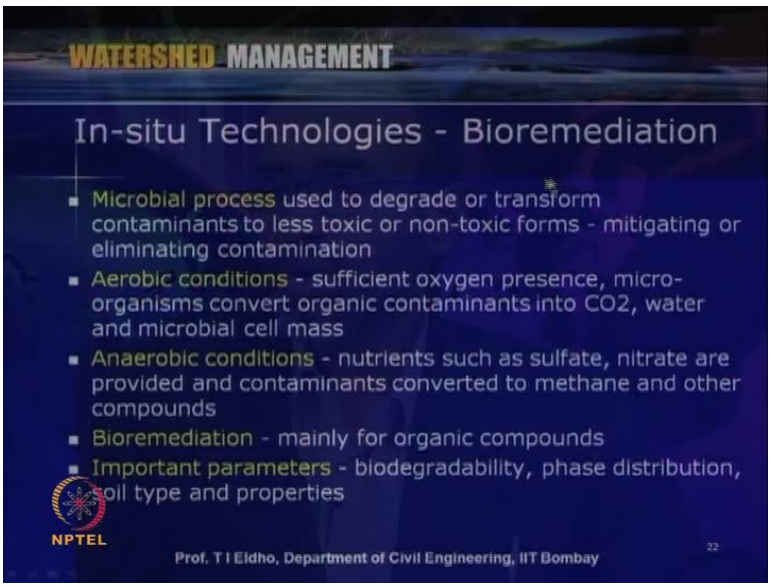

Now, let us look into some of the commonly used in-situ technologies. First one is called bioremediation. Bioremediation will be depending upon the contamination and depending upon the plume, we can identify certain microbial bacteria. So, activities of these bacteria can be enhanced within the aquifer system itself, so that the contamination is consumed by the bacteria and it will be converted into harmless products. Microbial processes are used to degrade or transform the contaminates to less toxic or non-toxic forms for mitigating or eliminating the contamination.

As far as microbial processes are concerned, it can be either aerobic condition, where sufficient oxygen is available. So, in sufficient oxygen presence, microorganism convert organic contaminants into carbon dioxide and water. This depends upon the microbial cell mass within the system. We can inject oxygen, so that the aerobic activities, aerobic conditions will be improved. Another one is anaerobic condition, where the microbial processes are enhanced without oxygen. So, nutrients such as sulphates, nitrates are

provided and contaminates are converted to methane and other compounds. This is what is done in anaerobic conditions.

This is a bioremediation and it can be either for aerobic conditions or anaerobic conditions. Bioremediation is generally used for organic compounds, organic contamination. Some of the important parameters that we have to identify, whether the contamination or the plume, which we considered is biodegradable, what is the phase of the distribution, we have to identify the soil type, then the properties of the aquifer. So, all these things are very important as far as the bioremediation, but this bioremediation is one of the cheapest techniques available as far as groundwater pollution remediation is concerned. Only difficulties that we have to identify for the given contamination of the plume is we have to identify what kind of microbial bacteria can be used for the remediation, how to enhance its activities within the aquifer systems. This is called bioremediation.

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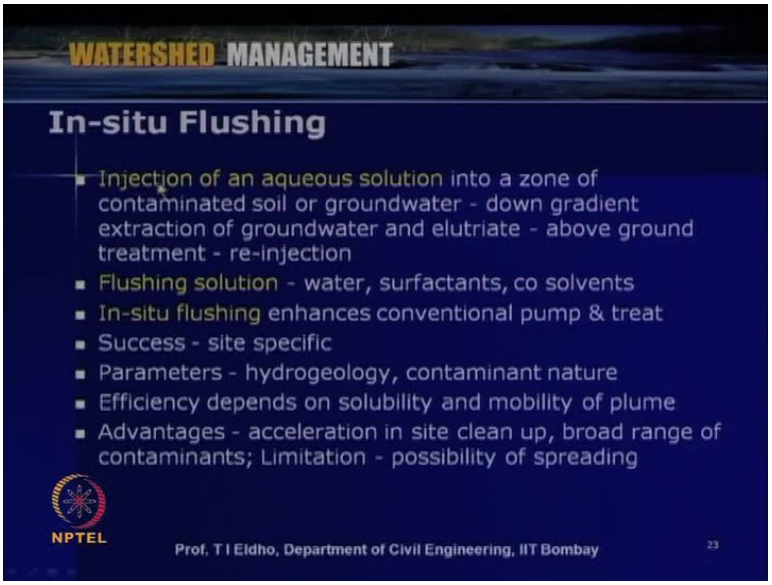

Some other techniques like in-situ flushing, for example, what we do here is we inject aqueous solution into a zone of contaminated soil or groundwater. In down gradient, we extract the polluted water, this water is treated and this can be re-injected. So, this is the technique of in-situ flushing. So, flushing solution can be simply water or we can introduce certain chemicals within the water called surfactants or co solvents. So, this may spill up the movement of the contamination to the pumping well.

The co solvents of surfactants can be also added within the systems. So, in-situ flushing enhances the conventional pump and treat. For example, it can be combined with the pump and treat and this is the success of the in-situ flushing. It depends upon the site like hydrogeology, contaminant nature, aquifer thickness and aquifer materials etc. So, the efficiency depends upon the solubility and mobility of the plume. Some of the advantages include acceleration in site cleanup, broad range of contaminants can be dealt with the in-situ flushing. Limitation - possibility of further spreading, when we are putting the water or the surfactants, there is a positive that the contamination can further spread to the aquifer system. So, these are some of the limitations as far as in-situ flushing is concerned.

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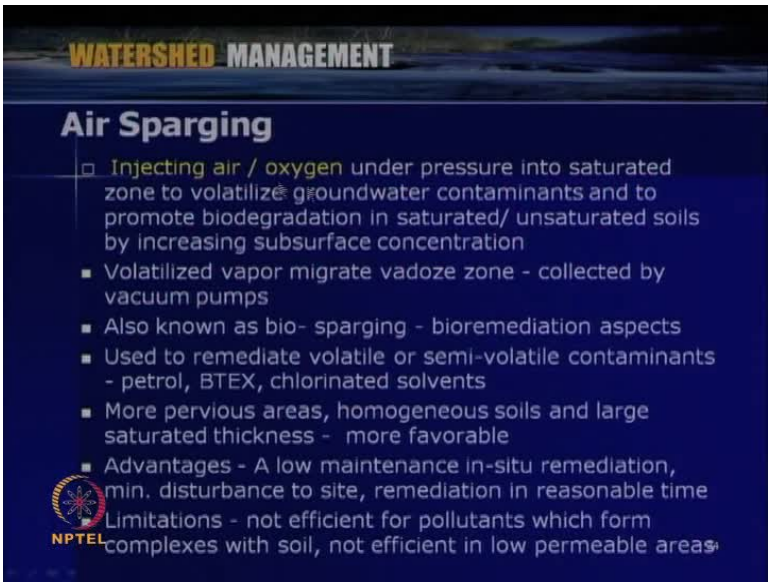

Another commonly used methodology is called air sparging. Here, what we do is we inject air or oxygen under pressure into saturated zone to volatilize the groundwater contaminants and to promote biodegradation in saturated or unsaturated soil by increasing subsurface concentration. Generally, this air sparging can be used for volatile organic contamination. The volatilized vapor migrates through the vadoze zone or the unsaturated zone and the vacuum pumps collect these.

Sometimes this air sparging is also called bio- sparging, since we introduce the air. The bioremediation process will also be enhanced within the system and then this air sparging can be used to remediate volatile or semi-volatile contaminants like petroleum

products, BTEX, benzene, toluene, some kind of pollutants, then chlorinated solvents etc. This is very effective in more pervious areas, homogeneous soils and large saturated thickness, air sparging is more effective.

Some of the advantages of the systems include low maintenance in-situ remediation, minimum disturbance to the site. Since if this process is once set, it will keep on going for long time without much interference. Remediation can be achieved in reasonable time. Some of the limitations include not efficient for pollutants, which form complexes with soil or not efficient in low permeable areas. So, mainly air sparging can be used for volatile organic contaminants.

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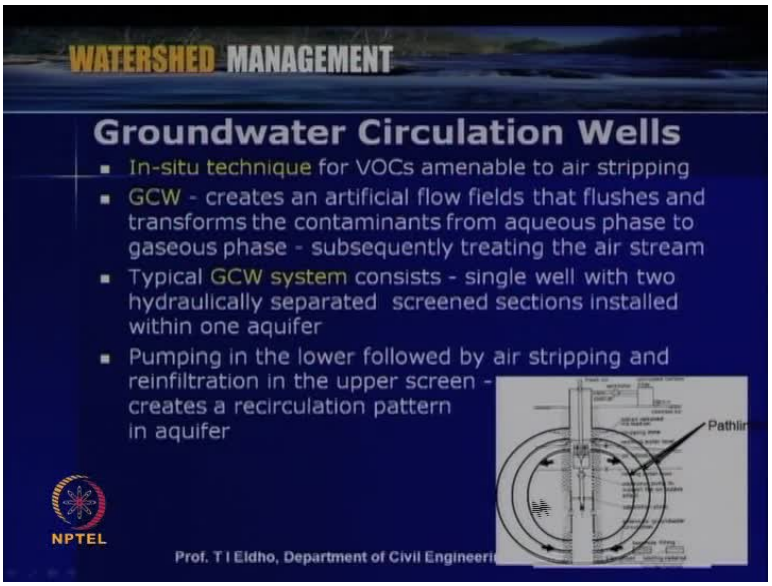

Another commonly used in-situ technique was developed in Germany. It is called groundwater circulation wells. This is an in-situ technique for volatile organic contaminants amenable to air stripping. Here, what do we say, if this is the hot spot of the contamination plume and this is aquifer system? There will be a pumping well and through that we create an artificial flow field that flushes and transform the contamination from aqueous phase to gaseous phase. Here, we strip with air and hydraulic gradient will be generated and these are path line that are shown. Water is again taken back here and then it will be circulated, so that is what is called as groundwater circulation well.

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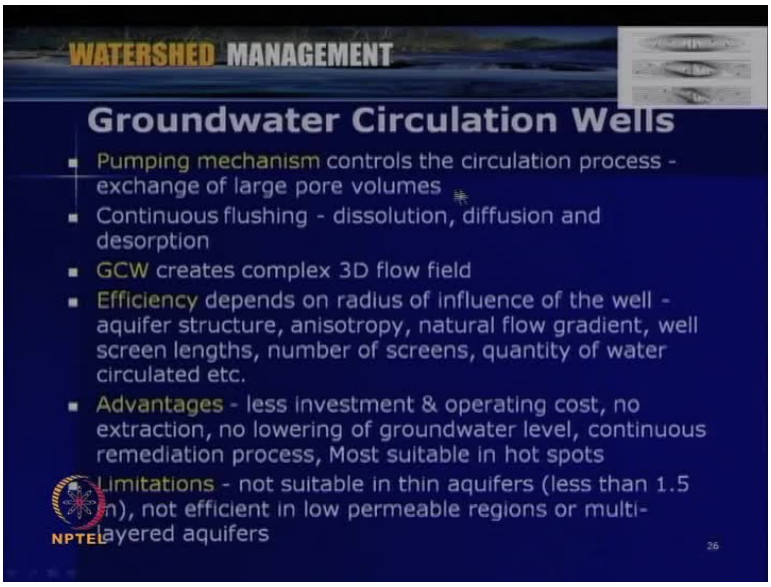

Typical groundwater circulation system consists of single well or two hydraulically separated or screened sections as shown in this figure. Pumping in the lower followed by air striping and re-infiltration the upper screen creates its recirculation pattern in aquifer systems. So, this is the typical pattern. Pumping mechanism controls this circulation processes and exchange of large pore volumes. So, continuous flushing, dissolution diffusion and desorption takes place. This creates a complex 3D flow field and the efficiency depends upon radius of influence of the well. So, this is the radius of the influence of the well, well screen length, number of screens etc.

Some of the advantages include less investment and operating cost, no extraction, no lowering of groundwater levels. Some of the limitations - it is not suitable in thin aquifer systems and not efficient in low permeable regions. This methodology is used mainly for volatile organic contaminants. We are discussing about how to remediate the groundwater contamination or how to remediate an aquifer systems.

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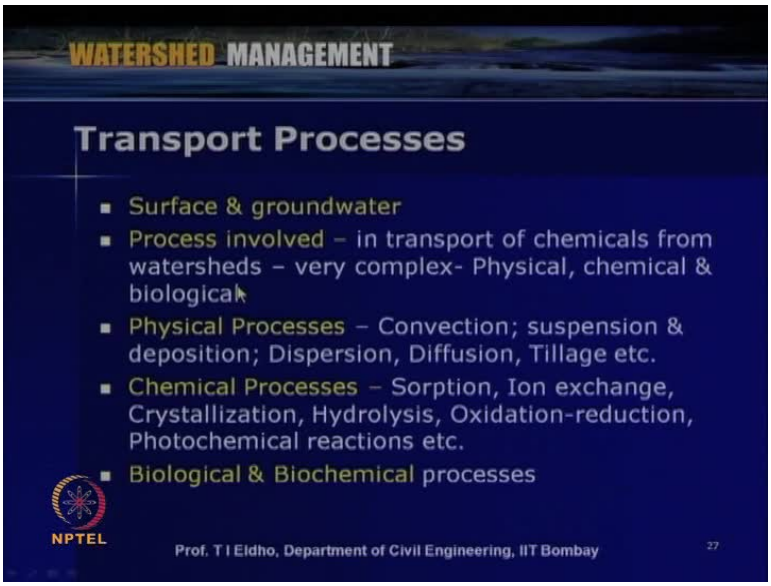

Let us see some of the transport processes taking place within aquifer or within surface water. So, what we are discussing is common to surface water as well as the groundwater systems. The process involved in transport of chemicals, for example, watersheds; these processes are very complex and the process can be either physical, chemical and biological. Some of the important physical processes can be convection, suspension, deposition, dispersion, diffusion, tillage etc and that is what is happening within the watershed. Chemical process can be sorption, ion exchange, crystallization, hydrolysis, oxidation, reduction, photochemical reaction etc. Third one is the biological or bio chemical processes. So, these are some of the important processes that are happening as far as the movement of the contamination within surface water or the groundwater is concerned.

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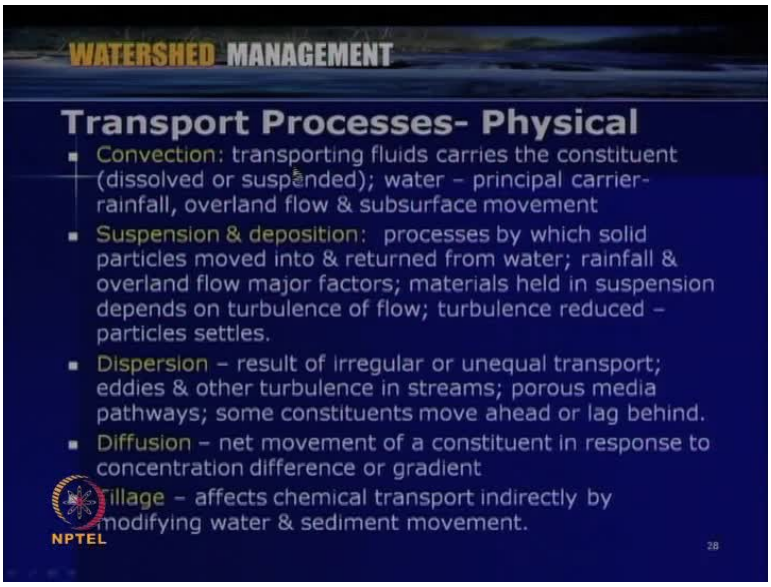

Let us look at some of the important details of this transport processes. As I mentioned, convection is transporting fluids. It carriers the constituents like either dissolved or suspended contamination. So, water is the principle carrier, since water is moving in surface water or in river or in aquifer systems. When the water is moving, the contamination is taken with that and it is the process of convection. Suspension and deposition means the process by which solid particles moved into and returned from water; it can be rainfall and overland flow. So, these are some of the major factors as far as suspension and deposition are concerned.

The materials held in suspension depend on the turbulence of flow, when the turbulence is reduced and the particle settles. For example, when rainfall takes place, the overland flow level keeps on increasing and depending upon the velocity of the turbulence, it can be generated. Suspension - when the velocity comes down, the turbulence is reduced so the particle settles or deposition takes place. Another important transport process is called dispersion. So, this is the result of irregular or unequal transport either in surface water or groundwater. Eddies and other turbulence in streams, in canals or the rivers and in porous media pathway, since the soil matrix is packed in such a way that it is a sinusoidal movement within the soil matrix. It can be a reason of the dispersion. Some constituents move ahead or lag behind.

Another one is diffusion process. Net movement of constituent is in response to concentration difference or gradient. So, this is the process called diffusion, then in watersheds like tillage affects the chemical transport indirectly by modifying the water and sediment movement. So, tillage means the soil surface pattern is the change by tilling, so that can affect the movement. These are some of the physical processes, which can take place as far as the transport is concerned either in surface water or groundwater.

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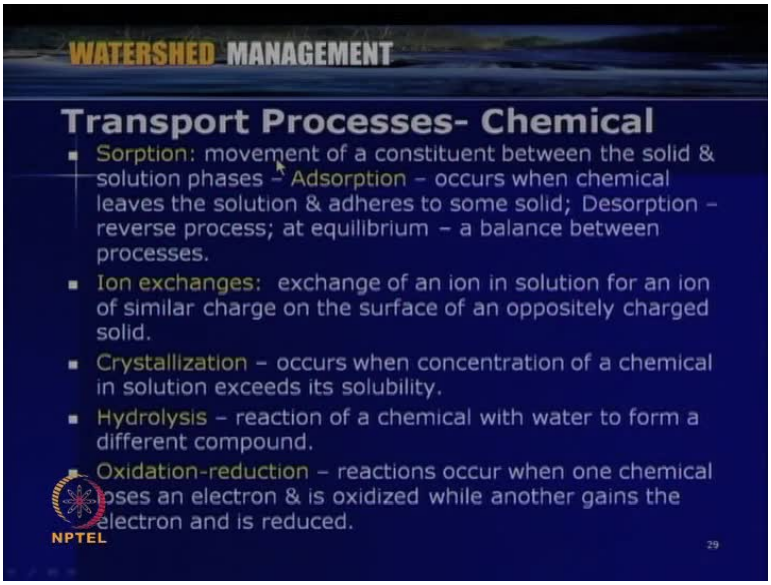

Now, as far as chemical processes are concerned, first one is sorption. This means the movement of a constituent between the solid and the solution phases. Sorption can be either adsorption. This occurs when chemical leaves the solution and adheres to some solid. It can be desorption, and it means the reverse process. So, at equilibrium, a balance between desorption or adsorption can take place. This is one of the important chemical processes.

Ion exchanges is the exchange of an ion in a solution for an ion of similar charge on the surface of an oppositely charged solid and this is called ion exchange. Crystallization occurs when concentration of chemical in solution exceeds its solubility. So, automatic crystallization starts, so that the concentration reduces. Another important chemical process can be hydrolysis. It is the reaction of chemical with water to form different compounds and it is the process called hydrolysis. So, this is also of a transport mechanism the chemical transport.

Oxidation and reduction reactions occur when one chemical loses an electron and oxidized, while another gains the electron and becomes reduced. So, these are some of the important chemical transport processes, which can take place either in surface water or in the groundwater.

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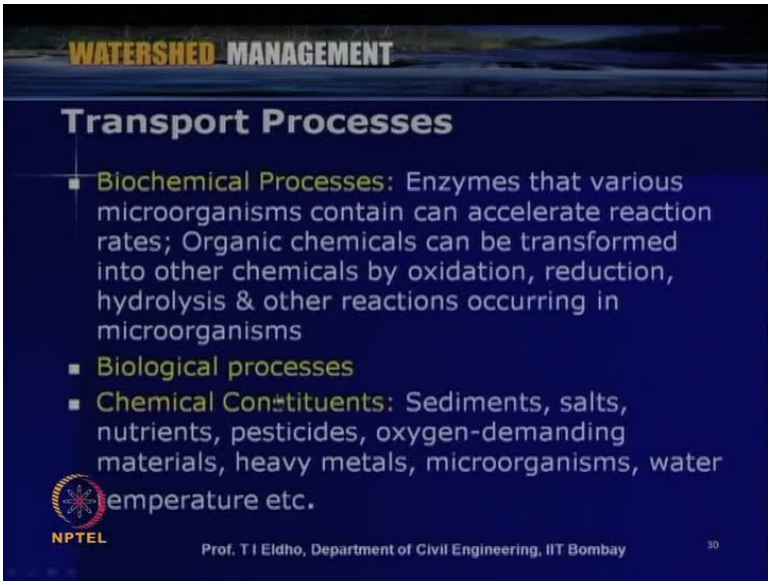

Some of the important process like biochemical processes, biological process. Biochemical processes: enzymes that various microorganisms contains can accelerate reaction rates; organic chemicals can be transformed into other chemicals by oxidation, reduction, hydrolysis and other reactions occurring in the micro organisms. Similarly, various biological processes like activities of bacteria or viruses can also change the transport phenomena that is happening within the surface water or ground water.

As we discussed that as far as the water is concerned, either surface or groundwater, some of the chemical constituents can be sediments, salts, nutrients, pesticides, oxygen-demanding materials, heavy metals, microorganisms, water, temperature etc. So, we have seen these details in the last lecture. Based upon this, we discussed in the last two lectures. Now, in the next lecture, we will be discussing the water quality analysis and water quality modeling with respect to this transport process, which we discussed in this lecture.

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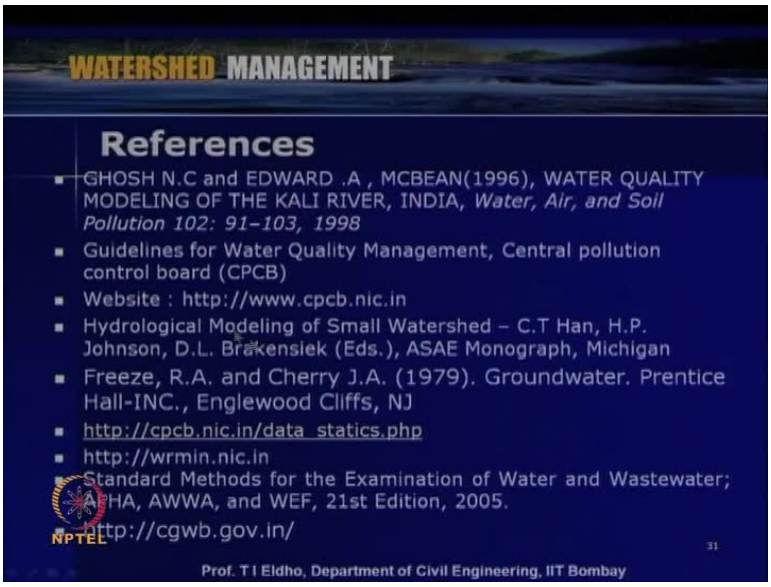

Now, some of the important reference used for today's lecture include some of the website from say central pollution control board, water resource ministry, groundwater board. Some of it is from Freeze and Cherry, groundwater and then guidelines for water quality management.

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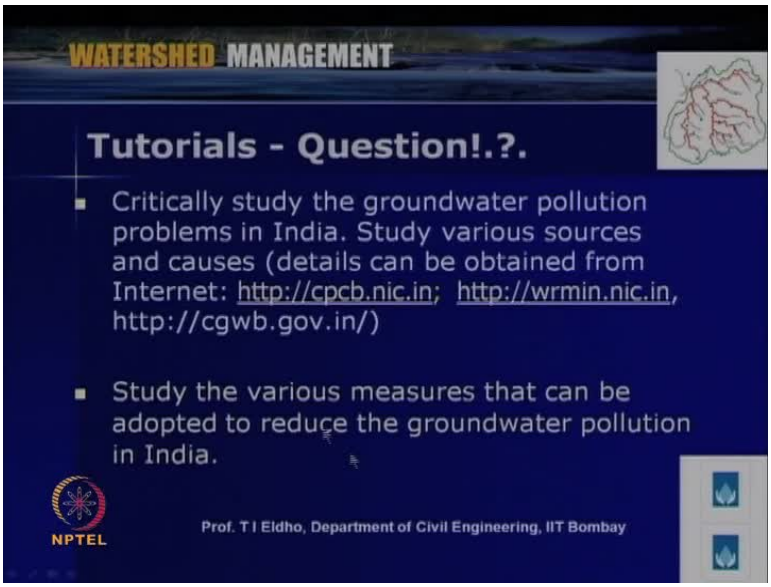

Some tutorial questions for today - critically study the groundwater pollution problems in India. Study various sources and causes. You can get the details from this cpcb or water

resource ministry website. Study the various measures that can be adopted to reduce the groundwater pollution in India.

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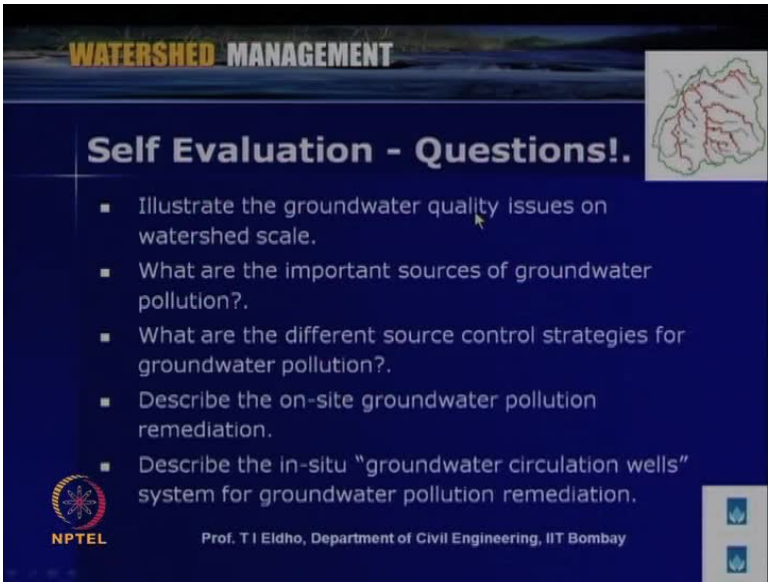

Some self-evaluation questions - illustrate the groundwater quality issues on watershed scale. What are the important sources of groundwater pollution? What are the different source control strategies for groundwater pollution? Describe the on-site groundwater pollution remediation. Describe the in-situ groundwater circulation wells systems for groundwater pollution remediation. You can easily answer these questions by going through the today's lecture.

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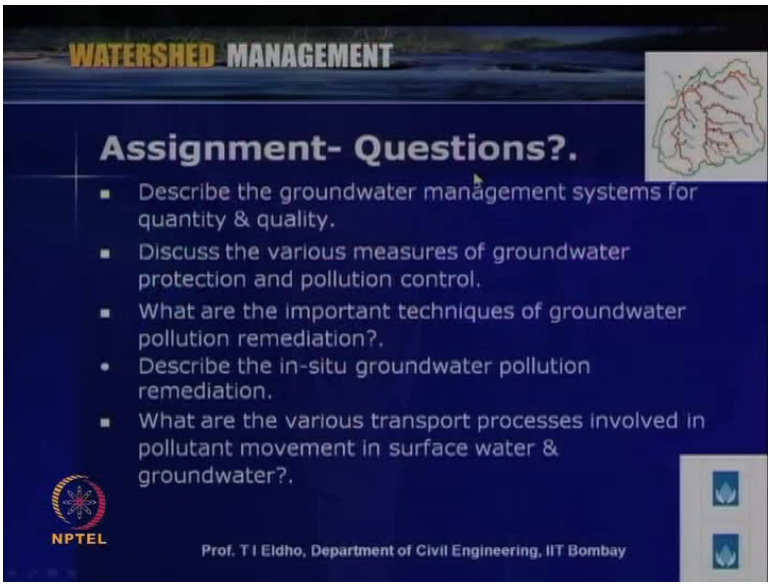

Few assignment questions like describe the groundwater management systems for quantity and quality. Discuss the various measures of groundwater protection and pollution control. What are important techniques for groundwater pollution remediation? Describe the in-situ groundwater pollution remediation. What are the various transport processes involved in pollutant movement in surface water and groundwater? All these questions can be answered by going through today's lecture.

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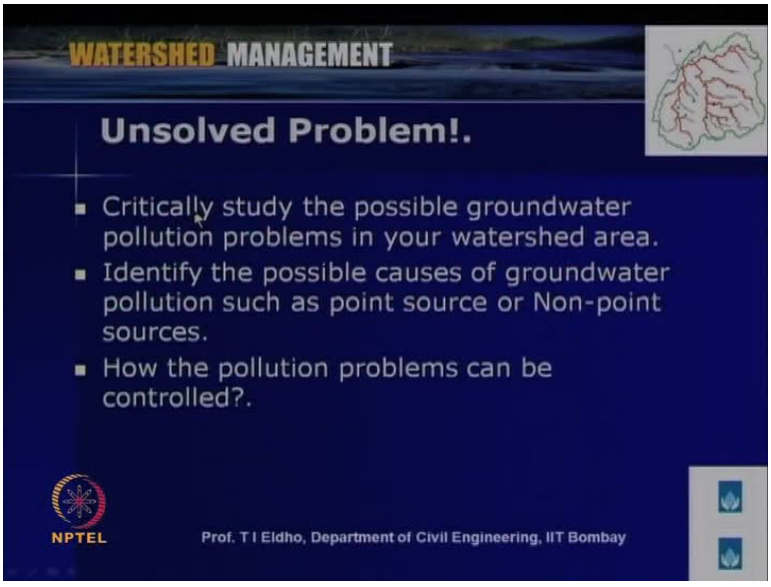

Finally, one unsolved problem - In your area and in your watershed, critically study the possible groundwater pollution problems. Identify the possible causes of groundwater pollution such as point source or non-point source agricultural sources or industrial sources. Study how this pollution problem can be controlled or what kind of remediation activities can be adopted, wherever pollution problems are there?

So, what we discussed today, include the groundwater pollution sources, pollution controlled and then remediation. We also we discussed about the transport processes taking place either in surface water or groundwater. In the next lecture, we will be discussing about the water quality modeling, how we can model either the pollutant movement in surface water or groundwater. Thank you.